Design Project – SIE 2023

EPFL

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Centre universitaire de médecine générale et santé publique · Lausanne

How to ensure the quality of measurements of a low-cost sensor network in Lausanne?

Introduction

Air quality monitoring plays a critical role in safeguarding public health and assessing the state of the environment. Poor air quality can significantly harm human health, leading to respiratory issues, cardiovascular problems, and other adverse health outcomes.

Traditional monitoring stations with precise and highly accurate instruments suffer from certain limitations:

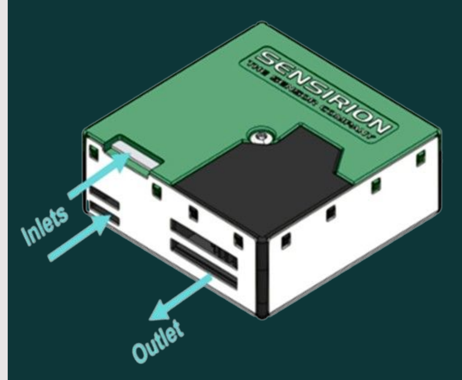
1. Cost: Traditional monitoring stations are expensive to establish, operate, and maintain.
2. Spatial coverage: The high costs involved in establishing and maintaining these stations often limit their numbers, resulting in sparse spatial coverage.
3. Temporal Resolution: Traditional monitoring stations generally provide hourly or daily averaged data. Such resolution may not capture short-term fluctuations or episodic events that can have significant health implications.

However, advancements in participatory science and the availability of low-cost sensors offer an opportunity to overcome these limitations. In Lausanne, Switzerland, a participatory science project called 'Captographie' was launched, involving the installation of several low-cost sensors in volunteers' homes. While the deployment of these sensors allows for improved spatial and temporal coverage of air quality data, the reliability and quality of the data generated by these low-cost sensors need to be assessed.

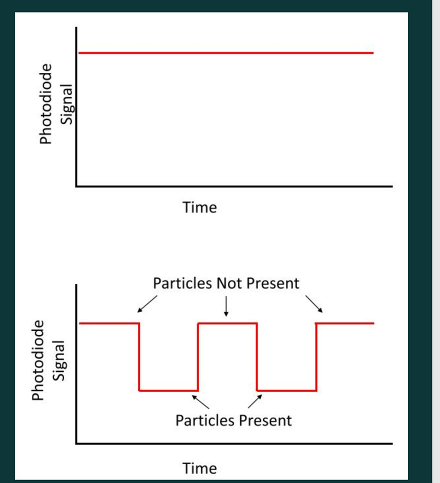
Objectives

- Understand the variability among different low-cost sensors and their relationship with official measuring stations.
- Develop a methodology to improve the quality of data produced by the low-cost sensor network, focusing on PM2.5 and PM10 measurements.
- Highlight the investigation of factors like humidity and temperature for their influence on sensor performance.
- Determine sensor correction factors.

How do these sensors work?



The majority of affordable particulate matter (PM) sensors utilize light scattering as their fundamental operating principle. These sensors require only three key components: a light-emitting diode (typically infrared or red), a phototransistor, and a lens to focus the emitted light from the diode. As particles pass through the measurement cavity, the intensity of the infrared/red light reaching the phototransistor is modulated due to the presence/absence of particles in the light path. This modulation, known as a nephelometric response, is directly related to the concentration of particles in terms of mass and number.



Methodology

1) Sensor colocation

Sensor colocation was conducted to assess inter variability among them. For that, the metrics of standard deviation (SD) and coefficient of variation (CV) between paired sensors which provide insights into measurement consistency and variability were computed.

⚠ The sampling times of Captographie and Lausanne low-cost sensors are different.

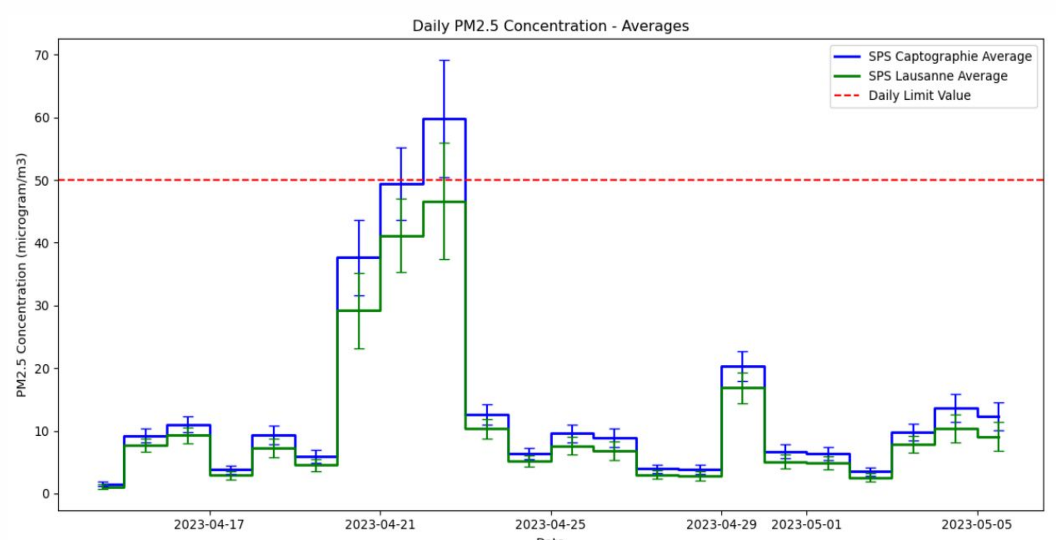
Captographie — 3 mins
Lausanne — 10 mins

Results

The variability of sensors can be due to:

- ❑ Age
- ❑ Sampling time
- ❑ Location
- ❑ Positioning angle

	Mean [µg/m³]	SD [µg/m³]	CV (%)
$PM_{2.5}$[µg/m³] (All sensors)	12.44	2.29	18.37
$PM_{2.5}$[µg/m³] (Lausanne sensors)	11.00	1.07	9.76
$PM_{2.5}$[µg/m³] (Capt. sensors)	13.88	0.71	5.08



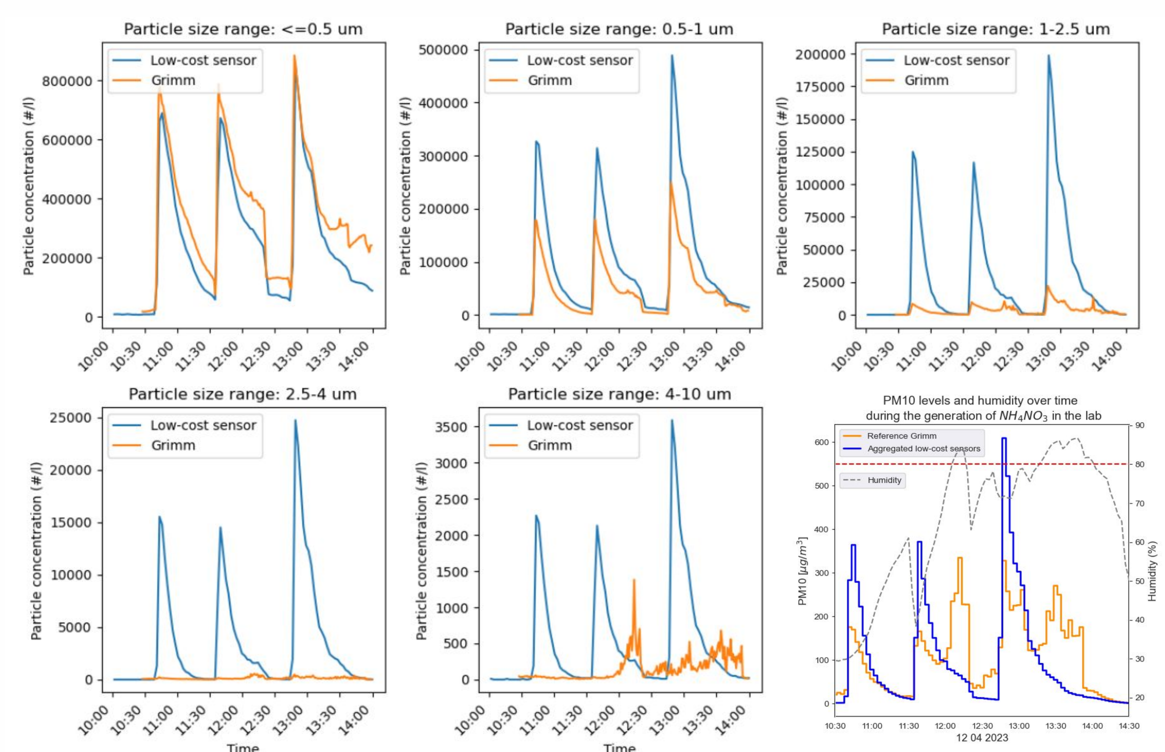
Time Series of the three-week-long sensor collocation.

✓ Lower sampling time is useful in capturing rapid changes in PM concentrations.

✗ Lower sampling time entails a larger amount of data.

2) Lab experiments

Extensive testing was conducted in the lab to assess the performance of the low-cost sensors. NH_4NO_3 and lactose particles were generated while the humidity levels were varied. The aggregated low-cost sensors were compared to a Grimm spectrometer which was considered the reference instrument



- Low-cost sensors seem to capture well smaller particle size ranges.
- Artifacts appear when humidity is higher than 75%.

Main Limitations Of Low-cost Sensors Found During The Lab

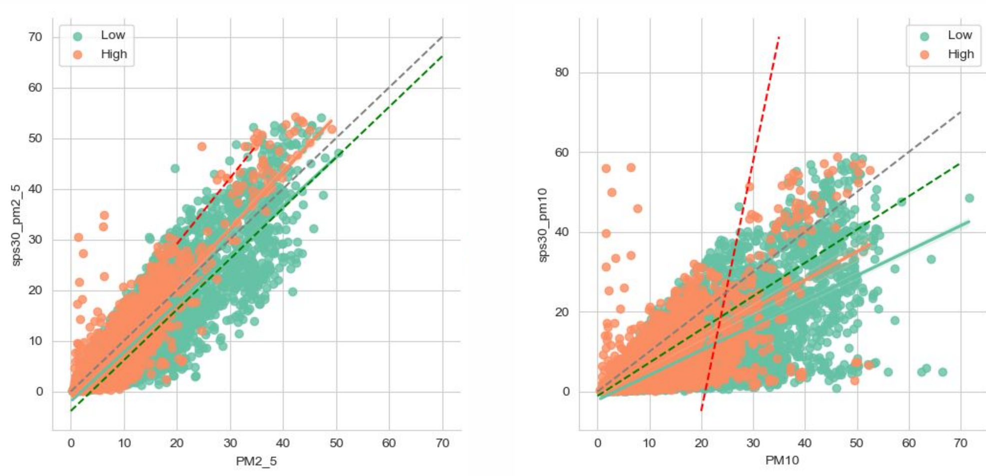
- Low-cost sensors capture only 3-5% of aerosol particles, requiring statistical methods for larger sizes. (Deviation for larger particles on the graph)
- High humidity significantly affects sensor performance during NH4NO3 generation due to particle growth from hygroscopicity.

3) Observational analysis

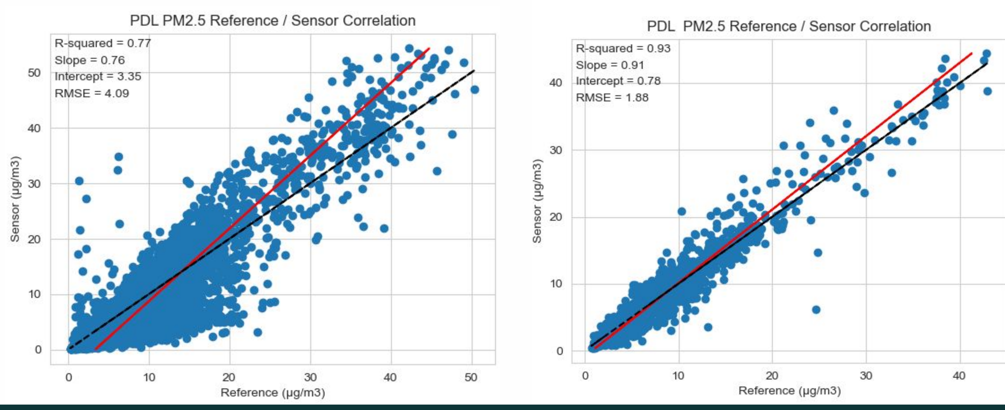
A comparison between the official stations of measurement and the neighbouring low-cost sensors was performed. The following analysis steps were carried out:

1. Time Series Plots
2. Distribution Plots
3. Performance Evaluation
4. Meteorological Influence
5. Machine Learning and Regression Analysis

A few correlation plots comparing reference and low-cost sensors.

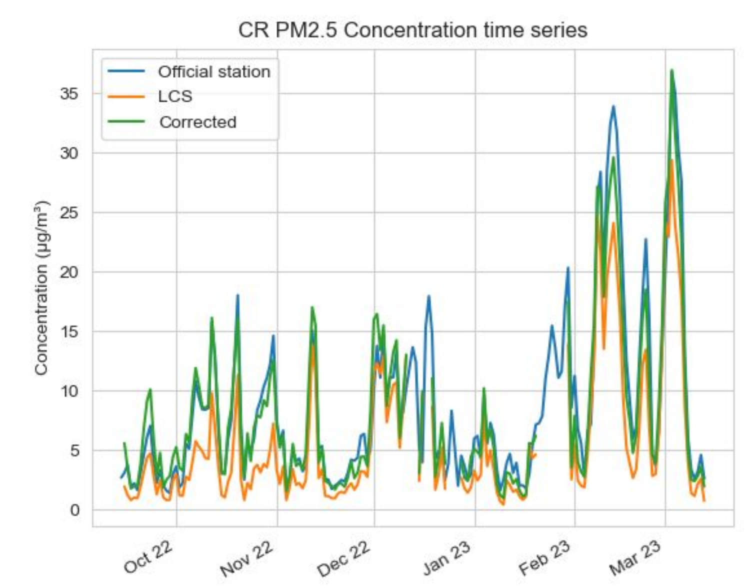


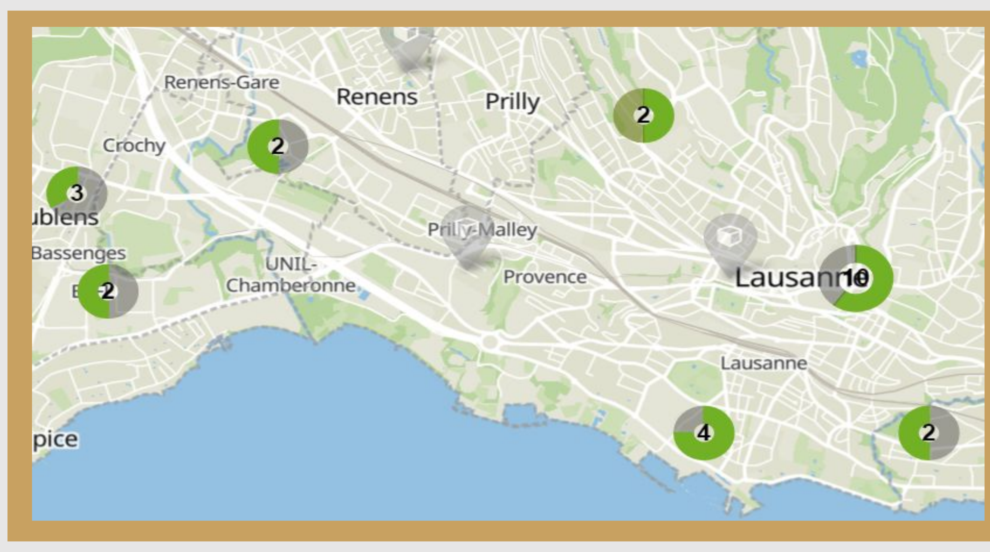
(Above) We see here the influence of high/low humidity on measurements, the dotted lines represent regression functions found in the lab.
(Below) Comparison between raw values (left) with corrected ones (right) after a Random Forest calibration



- Low-cost sensors struggle to accurately measure PM10 compared to PM2.5.
- Similar trends between urban stations (CR) and (PDL) indicate the influence of the environment on sensor performance.
- Reduction of the error with the Random Forest calibration

Application of the Random Forest calibration (trained on Plaines-du-Loup data) to César-Roux data





Access Live Data

Conclusion

This study highlights the performance and limitations of low-cost sensors for measuring PM concentrations. While sensors with low-sampling time capture rapid changes in PM, data processing becomes challenging due to the large volume of data generated. Variability among sensors emphasizes the need for careful data interpretation. Despite challenges in measuring PM10 accurately, low-cost sensors offer valuable insights for monitoring air quality and enabling participatory projects. They contribute to pollution maps and understanding of pollution distribution, especially in areas like Lausanne. Further research and collaboration are needed to enhance sensor accuracy in atmospheric monitoring.

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